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LIFE ON THE FRONTIER: AN INTERNATIONAL COMPARISON OF SCIENTISTS IN AN EMERGING FIELD

Koenraad Debackere
Rijksuniversiteit Gent

Michael A. Rappa
Massachusetts Institute of Technology

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LIFE ON THE FRONTIER: AN INTERNATIONAL COMPARISON OF SCIENTISTS IN AN EMERGING FIELD

Koenraad DEBACKERE and Michael A. RAPPA[†]
Massachusetts Institute of Technology

December 1991

ABSTRACT

This paper examines national differences in the performance of R&D activities of scientists in five major industrial countries: France, Germany, Japan, the UK, and the US. Evidence is presented from a recent survey of nearly 600 scientists working in the field of neural networks.

INTRODUCTION

Sociologists have long sought to understand the structure and dynamics of scientific and technological communities (for example, see Crane, 1972; Constant, 1980; Hagström, 1965; Hull, 1988; Thomson, 1988). Among scholars in the field there has been little disagreement over the international character of communities. Indeed Zaltman (1968) suggests that from the start, science has organized itself into international communities of researchers. Similarly, the increasingly international scope of industrial research and development activities has led management scholars to investigate the influence of national boundaries on the character and activities of scientists (for example, Westney 1992).

Although the international character of scientific and technological communities is widely recognized, comprehensive international studies of communities are often difficult to carry-out and are therefore fairly rare in the literature. Beyond the usual problems of language, the variation in standards and conventions for measuring and describing research-related activities in different countries makes any comparison especially difficult. For example, in their international study of research expenditures, Irvine et al. (1990) vividly illustrate the complexity that is frequently encountered when comparing national R&D systems.

A recent study of scientists in the neural network research community provides us with an opportunity to examine scientists across national boundaries (see Rappa and Debackere,

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[†] Koenraad Debackere is a Fulbright visiting research fellow at the Sloan School of Management, MIT. He is also a research associate with the Vlerick School for Management, Gent University, Belgium. Michael Rappa is an assistant professor with the Sloan School of Management, MIT.

1991). Although in our original study we investigated the characteristics of pioneering scientists in the field, the nature of our sample will allow for a detailed comparison of scientists across five countries: France, Germany, Japan, the United Kingdom and the United States. In particular, we will compare scientists in terms of the nature of their involvement in the field, their institutional context, the extent of their collaboration and information exchange activities, and their persistence in the field.

The Neural Networks Community

Before discussing the data, a brief discussion of neural networks is provided for the reader who is not already familiar with the field. A neural network is a type of information processing system that is inspired by models of the human brain. By using a biological model in its design, a neural network system has certain features that make it unique in form and function from conventional computers. For example, a neural network is not programmed in the usual sense, but rather it is trained with data. This implies that the computational performance of a neural network improves with experience: as it processes more and more information in performing a task, it becomes increasingly more accurate in its response. Another feature is its degree of parallelism in processing a task. Unlike a normal computer with a single or small number of sophisticated central processing units, a neural network has a very large number of simple processing elements that operate simultaneously on a computational problem. These features allow it to perform certain tasks that otherwise might be very difficult using existing computer technology. For further details, see DARPA (1988).

Neural networks have a long history of development, stretching back to theoretical explanations of the brain and cognitive processes proposed during the 1940s. In the early years, researchers formulated and elaborated upon basic models of neural computing that they then used to explore phenomena such as adaptive stimulus-response relations in random networks. By the 1960s there were several efforts to implement neural networks, the most notable being the single-layer "perceptron." Among neural network researchers the perceptron was considered a watershed, but at the same time it served as a lightning rod for criticism from researchers more interested in the burgeoning field of artificial intelligence. The idea of neural networks, as exemplified by the perceptron, quickly became seen as almost antithetical to the symbolic reasoning principles of artificial intelligence. Critical analysis of the perceptron led some highly respected AI researchers to proclaim that the concept was fundamentally flawed, and as such, inappropriate for researchers to waste much effort on. By casting doubt as to its legitimacy, antagonists of neural networks may have effectively dissuaded other researchers from entering the field in larger numbers (Minsky and Papert, 1988).

The controversy surrounding neural networks notwithstanding, work continued during the early 1970s with perhaps no more than a few hundred researchers worldwide in the field. Undeterred in their belief of the potential of neural networks, their persistence over the next decade eventually paid-off. By the 1980s, neural networks began to be viewed in a new light by researchers in a variety of disciplines, such that the field soon achieved a position of legitimacy within the scientific community. A professional society for neural network researchers was formed, specialized journals and books were published, and the first in a series of international conferences were held.

While it is difficult to explain exactly why the perception of the field changed so dramatically, at least four important technical events can be discerned: (1) the evolution of the single-layer perceptron into a multi-layer system; (2) the rapid development of related technologies that enabled researchers to develop, simulate, and diagnose neural networks of greater sophistication; (3) significant progress in theoretical understanding of neuro-biological processes; and (4) the contributions of researchers pursuing the idea of parallel distributed processing, the so-called PDP-group. In light of these developments, as well as others, interest in the field became widespread, such that the number of researchers working on neural networks expanded rapidly. By the end of the decade the size of the field swelled in membership from a few hundred to several thousand researchers worldwide.

METHOD AND SAMPLE

Through an analysis of published sources, including books, journal articles, and conference proceedings for the two-year period from 1988 to 1989, we identified more than 3,000 researchers worldwide working on the subject of neural networks. From this material, we were able to determine the exact address for each of 2,037 researchers in thirty-five different countries. Given the scope of the research community, a survey questionnaire was determined to be the most appropriate method of investigation. A twelve-page questionnaire in English was sent to researchers inquiring about (a) their neural network activities, (b) their decision to begin working on neural networks, (c) factors that might lead them to cease their neural network research in favor of another problem area, (d) their interaction with the rest of the neural network research community, and (e) their demographic characteristics. The questionnaire was pretested in the United States. Additional tests were conducted in Europe to reduce potential interpretational difficulties arising among those respondents for whom English is a second language.

Since there were thirty-seven researchers with more than one address during the time period considered, a total of 2,074 questionnaires were mailed in February 1990. After the third week of data collection, we mailed a follow-up letter and posted e-mail messages on computer bulletin boards to alert neural network researchers of the survey. Of the 2,074 questionnaires, 162 were returned as undelivered by the post office. None of the thirty-seven researchers with more than one address were represented in the undelivered questionnaires. At the completion of the data collection period approximately ninety days later, 720 of the 1,875 questionnaires presumed to be delivered were completed and returned, yielding a final response rate of 38.4 percent. Some of the factors that may have affected the response rate include: the length of the questionnaire, the global scope of the survey, and the institutional mobility of researchers.

The representativeness of the respondent sample was evaluated in three ways: by contrasting respondents to the original survey population in terms of their geographic distribution, their institutional distribution, and the distribution of their disciplinary backgrounds. In Tables 1 and 2, we report the geographic and institutional comparisons for both sets. For the geographic comparison, both the respondents and survey population were collapsed into four categories: North and South America, Europe, the Far East and the Middle East. For the institutional comparison, the respondents and survey population were classified as to whether they were employed in (a) universities, (b) commercial firms, and (c) other laboratories, which include a diversity of government-funded, non-academic laboratories. As can be seen, no statistically significant deviations could be detected between the respondent sample and survey population. An evaluation of the distribution of respondents in the sample and survey population according to disciplinary background also indicates no significant departure.

In terms of their position, 37 percent of the respondents hold faculty positions at academic institutions. The second most common position is that of staff scientist, which represents about 32 percent of all respondents. This is followed by students (17 percent), engineers (7 percent) and managers (5 percent). The average age of all respondents is 37 years, with a median of 35 years and a standard deviation of 9.2 years. The youngest respondent is 22 years old; the oldest 69 years. The majority of respondents hold a doctoral degree or are in the process of obtaining a doctoral degree (81.8 percent). Only

15.7 percent of respondents report having a master's degree. An absolute minority of 2.4 percent have a bachelor's degree.

Geographic classification:	RESPONDENT SAMPLE N	RESPONDENT SAMPLE %	SURVEY POPULATION N	SURVEY POPULATION %
North and South America	453	63.0	1393	67.2
Europe	181	25.1	444	21.4
Far East	73	10.1	209	10.1
Middle East	12	1.7	28	1.4

TABLE 1: *Geographic comparison for respondent sample and survey population*
(χ^2=5.24, n.s.)

Affiliation:	RESPONDENT SAMPLE N	RESPONDENT SAMPLE %	SURVEY POPULATION N	SURVEY POPULATION %
Universities	452	62.8	1399	67.5
Commercial firms	177	24.6	459	22.1
Other	91	12.6	216	10.4

TABLE 2: *Comparison of institutional affiliation for respondent sample and survey population*
(χ^2=5.61, n.s.)

Electrical engineers make-up the largest category of respondents (36 percent), and when added together with computer scientists they account for over 50 percent of the sample. Physical scientists (mostly physicists) make-up the second largest group of respondents, accounting for 19 percent of the sample. Biological scientists/engineers, mathematicians, and psychologists/cognitive scientists each account for less than 10 percent of the total sample.

A total of 89 respondents report positions with more than one employer. By taking both primary and secondary employers into account, a total of 220 universities, 101 firms, and 62 'other' institutions, most of which are government sponsored laboratories, are represented in the sample. On average, respondents have been involved with neural networks for 6.2 years (s.d.=6.1 years, median=4.0 years).

In our investigation we were unable to include all of the thirty countries represented in the sample. In most instances, the respondent pool for a given country was too small to be included in statistical comparisons. Thus, we decided to focus on the five countries most represented in the respondent sample: France, Germany, Japan, the UK and the US. The respondent distribution across the five countries, shown in Table 3, mirrors the distribution of neural network researchers in the survey population. The US is by far the largest group. As one might expect, these countries account for a large share of the world's total R&D expenditures (National Science Foundation, 1987).

Country	NUMBER OF RESPONDENTS	PERCENT OF TOTAL
France	47	7.9
Germany	30	5.0
Japan	59	9.9
United Kingdom	29	4.9
United States	430	72.3
TOTAL	595	100.0

TABLE 3: *Respondent distribution across the five most represented countries in sample*

RESULTS

General characteristics

We begin by comparing respondents across the five countries with respect to a number of general characteristics regarding their situation and work activities. First, in terms of the level of educational achievement, the portion of respondents who hold a doctorate (or are enrolled in a doctoral program) in France, Germany and the US ranges between 82 and 87 percent. In the UK this percentage is 96, and in Japan it is 63. A comparison across the five countries yields a statistically significant difference (χ^2=19.97; p<.001). Thus, Japanese respondents are less likely to have a doctorate than their colleagues in France, Germany or the US, while UK respondents occupy the other extreme of the spectrum.

The average number of years that respondents have been involved in neural networks in each country is given in Table 4. Respondents in Germany have the most number of years (eight on average), while those in France have the least number (about five). A one-way ANOVA test indicates that the difference between countries is not statistically significant. However, due to the large difference in the number of cases in each cell, one should be cautious in interpreting this result.

COUNTRY	YEARS OF INVOLVEMENT WITH NEURAL NETWORKS		
	MEAN	S.D.	N
France	4.98	3.5	46
Germany	8.00	6.5	27
Japan	7.42	4.1	57
United Kingdom	7.76	6.7	29
United States	5.96	6.0	420
ONE-WAY ANOVA	F(4, 574)=2.2974, n.s.		

TABLE 4: *Number of years respondent has been involved with neural networks*

An examination of the rate at which respondents in each country enter into the field of neural networks reveals some interesting differences. The cumulative entry of respondents is shown in Figure 1. The curves illustrated in Figure 1 are fairly similar for each country during the period between 1985 to 1989, when the increasing legitimacy of field led to rapid growth in the number of researchers working on neural networks. Before 1985 the entry profile is quite different. About 30 percent of the respondents in Germany, Japan and the UK started their neural network research activities prior to 1981. For the US, this total amounts to 15 percent, while in France it is about 10 percent.

Previous studies of scientists have emphasized diversity in research interests as a contributing factor in a scientist's productivity (Gieryn, 1978; Ziman, 1987; Root-Berstein, 1990). In this regard, we examined the extent of a respondent's involvement in neural networks relative to other topics. The results of a non-parametric Kruskal-Wallis comparison are shown in Table 5. French respondents are noteworthy in that nearly 33 percent of them consider neural networks to be their only research interest. By contrast, a majority of respondents in Germany, Japan and the UK view neural networks a as major research issue, but not a sole research issue. In the US, respondents show a wider pursuit of research interests than the four other countries, with most reporting neural networks to be one of many research issues they are currently investigating.

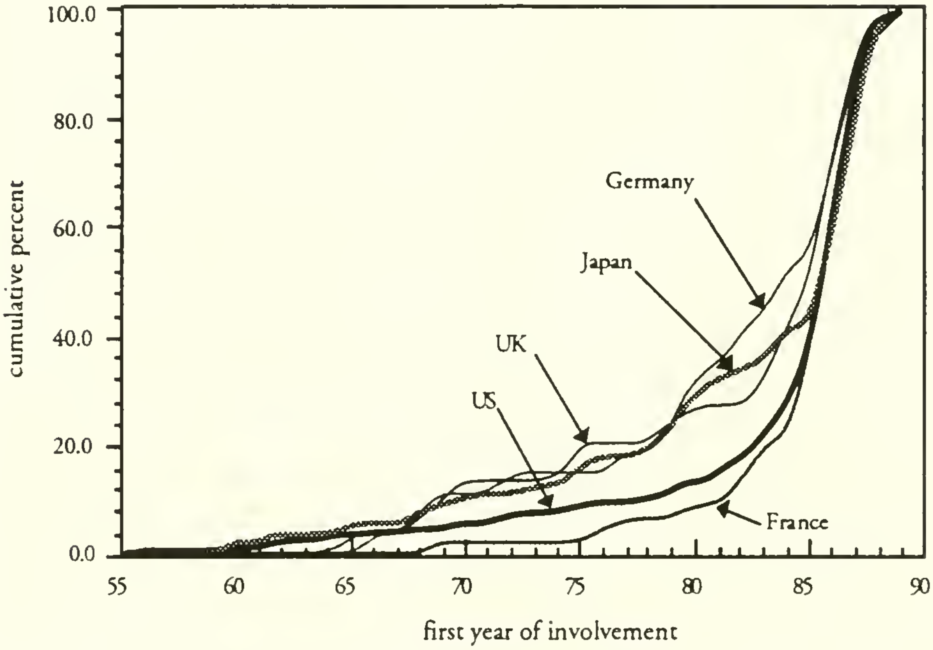

FIGURE 1: *Cumulative entry pattern for neural network researchers in five countries*

	KRUSKAL-WALLIS COMPARISON									
	FRANCE		GERMANY		JAPAN		UK		USA	
Neural networks are:	N	%	N	%	N	%	N	%	N	%
my only interest	15	32.6	2	6.7	5	8.5	4	13.8	46	10.7
a major interest	*15*	*32.6*	*19*	*63.3*	*34*	*57.6*	*15*	*51.7*	167	38.9
one of many	15	32.6	8	26.7	19	32.2	10	34.5	*180*	*42.0*
a minor interest	0	0	0	0	1	1.7	0	0	29	6.8
a topic to keep informed	1	2.2	1	3.3	0	0	0	0	7	1.6
K-W test	χ^2=16.90; p=.002									

TABLE 5: *Respondents' degree of involvement with neural networks (medians)*

The sectoral distribution of the respondents across academic, commercial, and other (mostly governmental) types of laboratories is shown in Table 6. Once again, some interesting differences appear. The majority of Japanese respondents are employed within firms, while nearly half of the French respondents are mainly affiliated with government-funded institutions (e.g., CNRS). Respondents from the remaining three countries are predominantly university-based, with Germany and UK having the highest percentages of academic respondents and the lowest percentages of commercial respondents.

	KRUSKAL-WALLIS COMPARISON									
	FRANCE		GERMANY		JAPAN		UK		USA	
Affiliation	N	%	N	%	N	%	N	%	N	%
Universities	16	34.0	*26*	*86.7*	25	42.3	*25*	*86.2*	*263*	*61.2*
Firms	8	17.0	2	6.7	*31*	*52.5*	1	3.4	122	28.4
Other	*23*	*48.9*	2	6.7	3	5.1	3	10.3	45	10.5

TABLE 6: *Comparison of affiliation for respondents across five largest countries*
(χ^2=95.26, p<.001; *modus*)

There is a slight difference in the age of respondents across countries, although a one-way ANOVA test is not statistically significance. The average age of respondents in France is 34 years old. UK and US respondents are on average 37 years old. Respondents in Germany and Japan are on average 39 years old. Similarly, in terms of the length of their professional experience (measured by the years elapsed since receiving their highest academic degree), the respondents do not differ significantly across the five countries. However, the percentage of respondents who are students or recent graduates ranges from about 20 percent in the US and the UK, to slightly more than 30 percent in Germany and France. Japan stands-out from other countries, with only 5 percent of respondents who are students or recent graduates.

In order to understand the theoretical or applied character of their work, respondents were asked to classify their activities according to a typology of neural networks proposed in the DARPA study (1988). Based upon this information, we categorized respondents according to whether they are: (1) involved solely in theoretical work, (2) involved solely in applied work, or (3) involved in both theoretical and applied activities. In each country, over 70 percent of the respondents are involved simultaneously in both theoretical and applied topics. No statistically significant differences can be found among the countries.

Given this basic understanding of how respondents in the five countries compare with respect to their demographic characteristics, we turn to an investigation of their collaborative and information exchange activities.

Collaboration and information exchange

The survey provided several different measures varying in intensity of respondents' collaborative and information exchange activities in neural networks research, including their attendance at conferences, professional society memberships, conference presentations, journal publications, and patenting. In addition, respondents were asked to identify formal collaborations with researchers in other organizations.

Respondents were asked to specify the number of neural network-related conferences they attended each year during the period from 1985 to 1989. In the first four years there are no significant differences among countries. However, in 1989 differences begin to emerge (F(4,585)=10.46, p<.001), with US respondents report attending an average of about two conferences, compared to an average of about two conferences for respondents from the other four countries. Statistically significant differences between countries also exist with respect to respondents' professional association memberships (F(4,565)=7.47, p<.001). On average, French respondents report the least average number of professional society memberships (1.24), while US respondents have the highest average number of memberships (2.31).

Clearly, conference attendance and association memberships provide only a limited indication of a respondent's inclination for exchanging information with others in the neural network community. We asked other questions that were designed to investigate specific information exchanges such as conference presentations, journal publications, research collaborations, amount of time spent communicating with researchers outside one's own organization and the diversity of these external communication partners.

In terms of respondents' publications and presentations over the previous five years, statistically significant differences exist between the five countries (p<.01 in both instances). The results of the one-way analysis of variance are shown in Table 7. US respondents have on average the lowest number of conference presentations and the second lowest average number of publications; whereas, French respondents have on average the lowest number of publications.

It should be noted that these comparisons were made by including respondents who were still graduate students at the time of the survey. Their inclusion lowers the publication and presentation averages. Repeating the analysis for the sample without students, the averages change, although differences remain statistically significant (well-below the p=.01 level). US researchers still report the lowest number of presentations but rank third for publications. Non-student respondents in Germany have both the highest number of publications and presentations.

	ONE-WAY ANOVA COMPARISON									
	FRANCE		GERMANY		JAPAN		UK		USA	
	MEAN	SD; N	MEAN	SD; N	MEAN	SD; N	MEAN	SD; N	MEAN	SD; N
Presentations	5.17	3.6; 47	6.23	3.5; 30	6.31	4.0; 59	6.00	3.6; 29	4.49	3.4; 426
Publications	1.57	2.4; 44	4.17	4.0; 29	2.28	2.8; 58	3.07	3.8; 28	2.19	2.9; 416

TABLE 7: *Publications and presentations for respondents across five largest countries*
(Presentations: F(4,586)=5.70, p<.001; Publications: F(4,574)=4.12, p<.01)

We also investigated respondents' patenting activity. It is interesting to note that academic and commercial respondents alike are employing all three mediums—patents, publications, and presentations—in their attempt to protect claims to important research findings. The average number of patents per respondent is very low. This is not surprising given the relative commercial infancy of neural network technology. At the same time, however, significant differences exist across the five countries. Among Japanese respondents, 61 percent report holding at least one patent. This compares with 13 to 22 percent for the other four countries in the sample. The difference is highly significant (χ^2=47.89; p<.001). Thus, Japanese researchers stand out among their colleagues as far as patents are concerned.

Collaboration with research teams outside one's organization is perhaps the most intensive and direct form of information exchange behavior we investigated. We asked respondents to report whether or not they are involved in collaborative research projects on the topic of neural networks with researchers in other institutions. The highest number of collaborations occur among UK respondents, with 68 percent of the respondents involved in collaborative research. This compares with 41 percent of German respondents, 34 percent of Japanese respondents, 57 percent of French respondents, and 36 percent of US respondents. The difference between countries is significant (χ^2=18.20, p=.001).

The amount of multinational collaboration among respondents is highest for the European countries. Slightly more than half of the respondents in France and England who collaborate with other teams are involved with researchers outside their respective countries. Two-thirds of the German respondents who are involved in collaborative research are engaged with teams outside of Germany. By contrast, Japan and the US domestic collaborations predominate. Among Japanese respondents involved in collaborations, 80 percent collaborate solely with research teams within Japan. In the case of US respondents involved in collaborative research, 92 percent are domestic collaborations. As might be expected, geographic proximity it relevant: for the three European countries, collaborations usually involve other Europeans. Collaborative efforts involving Japanese teams are an absolute minority, with only one French respondent and one US respondent each reporting a joint project with a Japanese research team.

Respondents also reported the number of hours per week they exchanged neural network information with researchers outside their organization and the diversity of their external communication partners. The average number of hours spent per week in talking about neural network research with researchers outside their organization was not significantly different across the five countries. The range was between one and two hours per week on average. As far as diversity of communication partners is concerned (as measured by the number of different researchers outside their organization), the differences between countries are statistically significant (see Table 8).

Respondents were asked to rank order five possible actions they might take after making an important advance in neural networks. They were able to choose between immediately publishing the result in a rapid publication journal, announcing it publicly at a press conference, seeking patent protection, assessing its potential commercial value, or disseminating it to other researchers in the field via telephone, fax or computer network. The results for the five countries are shown in Table 9.

As can be seen in Table 9, publishing is ranked as the highest priority of respondents in each country. The press conference announcement is ranked as a lowest priority, except for the Japanese researchers. Commercial objectives occupy the middle range, although in the case of the US and Japan, seeking patent protection is ranked as a higher priority than disseminating the results to other researchers.

	KRUSKAL-WALLIS COMPARISON									
Number of researchers	FRANCE		GERMANY		JAPAN		UK		USA	
	N	%	N	%	N	%	N	%	N	%
None	5	11.1	0	0.0	6	10.2	0	0.0	65	15.5
1-to-5	24	53.3	20	71.4	37	62.7	14	51.9	264	62.9
6-to-10	14	31.1	7	25.0	15	25.4	8	29.6	60	14.3
11-to-15	0	0.0	0	0.0	1	1.7	2	7.4	14	3.3
16-to-20	2	4.4	0	0.0	0	0.0	1	3.7	3	0.7
More than 20	0	0.0	1	3.6	0	0.0	2	7.4	14	3.3
K-W test	χ^2=16.91, p=.002									

TABLE 8: *Kruskal-Wallis comparison for diversity of external communication partners*

	RANK ORDER OF DISSEMINATION PREFERENCES				
	FRANCE	GERMANY	JAPAN	UK	US
publishing in rapid publication journal	1.32	1.25	1.57	1.69	1.76
disseminating to other researchers	2.73	2.56	3.37	2.00	2.85
seeking patent protection	3.23	3.56	2.94	3.38	2.79
assessing potential commercial value	3.61	3.44	3.94	3.31	3.15
announcing publicly at press conference	4.11	4.19	3.17	4.62	4.44
Kendall Concordance W*	.4612	.5237	.3100	.5649	.3760
Number of cases	28	16	35	13	230

TABLE 9: *Mean ranks on respondents' preferences for disseminating findings for each country*
(1=highest priority; 5=lowest priority; *all significant below .001)

Apparently, differences in information exchange behavior exist among the researchers in the five countries surveyed above. However, a number of similarities are also striking. More specifically, all respondents consistently rank publishing their research results as their highest priority. Although the diversity of external communication partners may differ across countries, the amount of time spent in communicating with researchers outside one's organization is roughly similar. Finally, significant differences exist between the five countries as to whether or not researchers are involved in collaborative projects with teams outside their organization. For researchers involved in such collaborations, the degree to which these collaborations are nationally focused is remarkable for both Japanese and US respondents.

Persistence in the field

A final topic which deserves our attention is the issue of persistence; namely, how long are researchers in the different countries willing to continue with their neural network research agenda before leaving to pursue other research avenues? Respondents were asked to indicate how long they would be willing to continue working on the topic of neural networks in order to reach their goals, given current progress. The results are shown in Table 10. Most respondents would be willing to remain with neural networks for two-to-five years. This result is consistent across all countries except one: a majority of Japanese respondents (54 percent) indicate a willingness to continue working on neural networks for more than five years. By contrast, German respondents indicate the least patience for remaining with neural networks. The percentage of respondents in the other countries who would be willing to continue for five years or more is: UK (42 percent), US (40 percent), France (30 percent) and Germany (21 percent).

Number of years:	KRUSKAL-WALLIS COMPARISON									
	FRANCE		GERMANY		JAPAN		UK		USA	
	N	%	N	%	N	%	N	%	N	%
< 1 year	4	8.7	0	0.0	0	0.0	1	3.8	18	4.4
1-to-2 years	8	17.4	8	28.6	6	10.2	1	3.8	67	16.4
2-to-5 years	*20*	*43.5*	*14*	*50.0*	21	35.6	*13*	*50.0*	*159*	*39.0*
5-to-10 years	7	15.2	3	10.7	*19*	*32.2*	2	7.7	70	17.2
> 10 years	7	15.2	3	10.7	13	22.0	9	34.6	94	23.0
K-W test	χ^2=11.37; p=.02									

TABLE 10: *Number of years respondents are willing to continue work on neural networks given current progress* (column percentages add to 100 percent, ***median*** values)

DISCUSSION

The foregoing analysis highlights a number of similarities and differences that exist among neural network researchers in France, Germany, Japan, the United Kingdom, and the United States. Clearly, any conclusions drawn from the data should be made cautiously, in light of the predominance of US researchers in the sample. While it certainly would have been preferable to have a more evenly distributed number of respondents in each of the five countries, the respondent sample nonetheless corresponds with the geographic distribution of the sample population. Indeed, the fact that the US accounts for such a large share of the global neural networks community is an interesting finding in and of itself. Evidently, the US commitment to pursue emerging technologies is, at least in this instance, quite strong.

In the picture that emerges from the data, one is struck by the strength of the commercial orientation of Japanese respondents toward neural networks in comparison to respondents in other countries. Japanese respondents are more likely to be found working in commercial laboratories as opposed to universities or government laboratories. Given this situation, it is understandable that Japanese respondents hold more patents on average than their counterparts in other countries, and (along with the US) rank patent protection as their secondest highest priority upon making an important development. It is also noteworthy that Japanese respondents are less likely to hold a doctoral degree, implying that much of their practical research training is acquired within a commercial context and not an academic one. The prevailing opinion that Japan is more adept than most countries are at moving scientific results into commercial applications would seem to be born-out by these findings.

The attitude of Japanese respondents toward continuing with their research in neural networks also appears to confirm the widespread view that Japan approaches the development of new technologies with a longer-term perspective than other countries (Dore, 1987; Dertouzos, et al., 1989). However, it is interesting to note that Japanese respondents differ very little from other other respondents (especially those in Germany and the UK) in terms of their average length of involvement in the neural networks to date. Furthermore, an examination of the cumulative entry of respondents into the field of neural networks suggests that Japan, like Germany and the UK, experienced a relatively more gradual growth in its neural network research community. By contrast, France and the US experienced slower growth initially, followed by a tremendous increase in researchers in the 1980s.

With respect to collaborative research across organizations, respondents in the European countries appear to be most active. Moreover, the collaborations that Europeans are engaged in are more likely to take them across national borders. By contrast, we find that collaborative research is to a large extent domestically-based in Japan and the US. Interactions between Japan and the four other countries are extremely limited. In Europe, multinational research projects mainly involve other European partners. A total of ten European respondents explicitly mention their involvement with other European partners through joint projects such as ESPRIT. Given the national focus of most collaborations, one may speculate that supranational research efforts such as ESPRIT can indeed justify their existence, if only because they provide researchers an opportunity to become part of an international network of R&D collaborations.

The data presented in the paper provide some insight into the attitudes and research behavior of scientists. However, any judgment as to the strength of these conclusions will have to await the investigation of other fields in order to test for external validity. While it is tempting to extrapolate the present evidence in order to characterize national R&D systems, a more thorough consideration of the experience in each country is clearly warranted. Thus, it is important that the findings in this paper be left to scholars who are experts on the respective countries. While some findings will undoubtedly confirm existing opinions, other findings may lead to new debates among those who are interested in comparing national R&D systems.

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